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COEFFICIENT OF RESISTANCE TO MOTION OF BURNING PARTICLES

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ABSTRACT

An experimental analysis is carried out to compare the drag coefficients of burning and non-burning spherical carbon particles. The experimental data pertain both to the stationary and non-stationary states. As a rule the latter states occur when solid fuel is burned in various heating installations. /12*

1. The Drag of Burning and Non-burning Spherical Carbon Particles which are Fixed in a Flow

The purpose of the experiments has been to measure directly the drag of burning and non-burning spherical carbon particles and to clarify the variation in the drag coefficient as a function of the Reynolds number.

A pendulum balance was used in an experimental set-up shown in figure 1. This balance consisted of a thin quartz rod 2, suspended horizontally by means of threads having a length of L = 287 cm. One end of the rod contained a spherical carbon particle 1, and the flow of the oxidizing atmosphere around this particle was controlled by means of flow meter 7.

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*Numbers given in margin indicate pagination in original foreign text.

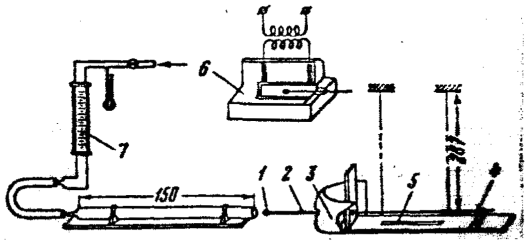

Figure 1.

This balance design had made it possible to establish the force acting on a particle by measuring the displacement from the position of equilibrium and using the following equation:

$$F = P \tan \alpha$$

where P is the weight of the particle and the rod, α is the angular displacement from the equilibrium position. The conditions of the experiment made it possible for us to assume that $\tan\alpha \sim \sin\alpha \sim l/L$, where l is the displacement from the null position measured by means of scale 5.

To prevent the lateral displacement of the pendulum graphite guide rods 4 were installed. The error in the reading of the balance did not exceed 1.5 percent.

The carbon spherical particles were pressed from a mixture of coal carbon and 15 percent peat tar which served as the binding material. After pressing the particles were heated to 900°C in the absence of air.

Experiments with the burning particles were preceded by the heating of the particles in a muffle furnace 6 up to a temperature of 900°C. The value of the drag coefficient was obtained from the expression $c = F/0.5\rho v^2 s$, where ρ is the density of the oxidizing atmosphere, v is its velocity and s is the cross section of the particle. The gas parameters were specified for room temperature. The experiments were conducted in the center of the flow inside the tube and outside the tube (in the latter case the particles were placed at a distance of two diameters from the tube end).

The tube diameter was 42 mm, while the particle diameter was 15.5 mm. The duration of the experiment was limited by the time during which there was little change in the diameter of the particle.

The analysis of experimental data pertaining to experiments at the center of the flow (the particle was placed at a distance of 1.5 diameters from /13 the end of the tube), which is presented in figure 2, shows that the variation in the drag coefficient of the burning particle as a function of the Reynolds number R is in complete agreement with a similar variation for the case of the non-burning particle (within the limits of experimental error, which is 8.5 percent). The light and shaded circles correspond, respectively, to the burning and non-burning particles. The experiment did show that the walls have a substantial effect on the drag coefficient.

Figure 3 shows the variation in the drag coefficient for burning (broken line) and non-burning particles as a function of their position with respect to the end of the tube, when the Reynolds number is constant R = 5400. As we can see from this figure the value of the drag coefficient is constant at the center of the flow up to a distance of one diameter from the end of the tube

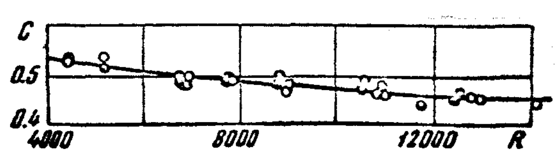

Figure 2.

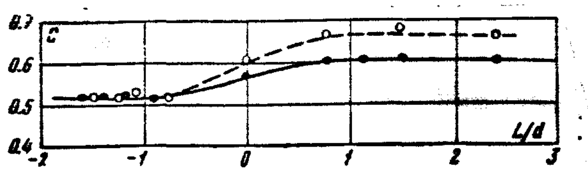

Figure 3.

(left part of the curve). At this point it begins to increase as the end of the tube is approached, and finally inside the tube at a distance of one diameter it becomes constant. In this case, as we can see from figure 3, when the particle is inside the tube the burning process has an effect on the drag of the particle, increasing it by 12 percent with respect to the drag of the non-burning particle. It should be pointed out that under the conditions of the experiment the cross section of the particle was 13 percent of the tube cross section. This produced an increase in the flow velocity, i.e., an increase in the effective Reynolds number of the experiment. Therefore, the data presented in figure 3 must be regarded with certain reservations. We should also note that in the case of the burning sphere the Reynolds number was computed using the parameters of the cold gas, which is not entirely correct, if we consider the relative dimensions of the tube diameter and of the particle.

It has not been possible to specify the gas parameters for determining the true Reynolds number in these experiments. Consequently the conclusions made in this work should be viewed with this in mind.

The effect of particle surface temperature on its drag coefficient was also studied experimentally.

The variation in the surface temperature of the particle (from 900 to 1250°C) was achieved by enriching the oxidizing atmosphere with oxygen. The results of these experiments are shown in figure 4. The surface temperature of the particle was measured by means of an optical pyrometer.

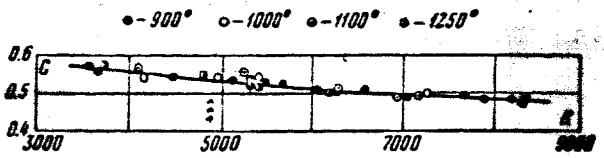

Figure 4.

2. Investigation of the Motion of Non-burning and Burning Spherical Particles

From the practical standpoint it is expedient to study the hydrodynamic properties of burning particles in their natural state, i.e., when they are moving freely in the oxidizing atmosphere. For this purpose experiments were conducted to investigate burning and non-burning particles. The particles /14 were fed separately into a glass tube from a special rotating feeder which had the form of two hollow cones connected at the base by means of a ring with holes. The rings with holes were replaced depending on particle diameters. Feeder rotation was effected by an electric motor. Spherical particles (d = 4.5, 4.0, 3.2 and 2.4 mm) of electrode carbon were the test particles.

The relatively low velocities of the particles (up to 7 m/sec) made it possible to register them using the simple method of photographic scanning. The motion of the particles was fixed on a photographic film which was moved uniformly in a direction perpendicular to the direction of motion.

The glass tube (D = 36 mm, l = 176 cm), which was used to study the particles, was illuminated along its entire length with daylight lamps. Screens made from black photographic paper were installed to prevent the multiple scattering of light from the lamps by the walls. By arranging the lamps and the screens in a special way it was possible to illuminate only the central part of the tube and consequently to record only those particles moving along the axis of the tube. As shown experimentally, with this method of illumination it was possible to record only those particles which did not deviate from the axis of the tube by more than 3 mm. The velocities of the particles were determined from the slope of the track with respect to the direction of motion of the film which rotated with a constant speed.

The speed of the film was controlled by maintaining a constant pattern on a stroboscopic disc mounted on the motor driving the film.

Figure 5 shows the variation in the velocity of a particle having a diameter of 2.4 mm as a function of the distances which it travels for different values of the flow velocity w. Experiments with burning particles were conducted in the same manner as experiments with non-burning particles.

The spherical carbon particles were placed into the rotating feeder which was in a heating furnace. The temperature of the particles was raised to 900°C after which time they were fed individually into the glass tube. To prevent the burning of the particles during their heating nitrogen was passed through the feeder.

Figure 5 also shows the experimental data corresponding to experiments with burning particles conducted at the specified flow velocities.

Similar data showing the agreement in the laws of motion for non-burning and burning particles were obtained for other particle diameters (d_r = 4.5, 4.0, 3.2).

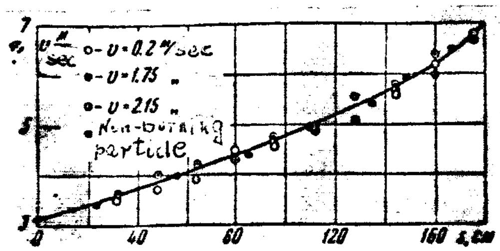

Figure 5.

Conclusions

The variation in the drag coefficient of a burning particle fixed in the flow as a function of the Reynolds number is the same as for the case of a non-burning particle. The variation in the surface temperature of a burning particle from 900 to 1250°C has no effect on the drag coefficient. The investigation of the motion of burning and non-burning spherical particles whose diameters were in the range 2.4 to 4.5 mm did not detect any difference in their motion. As a result of this the conclusions presented in reference 1 concerning the increase in the drag coefficient of burning particles were not confirmed.

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